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Wood

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(54) **REDUCED DRAG PROJECTILE**

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F42B 10/32 (2006.01)

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CPC ***F42B 10/46*** (2013.01); *F42B 10/32* (2013.01)

(58) **Field of Classification Search**
CPC F42B 10/46; F42B 10/00; F42B 10/32; F42B 10/38; F42B 30/02; F42B 5/02
USPC 102/439
See application file for complete search history.

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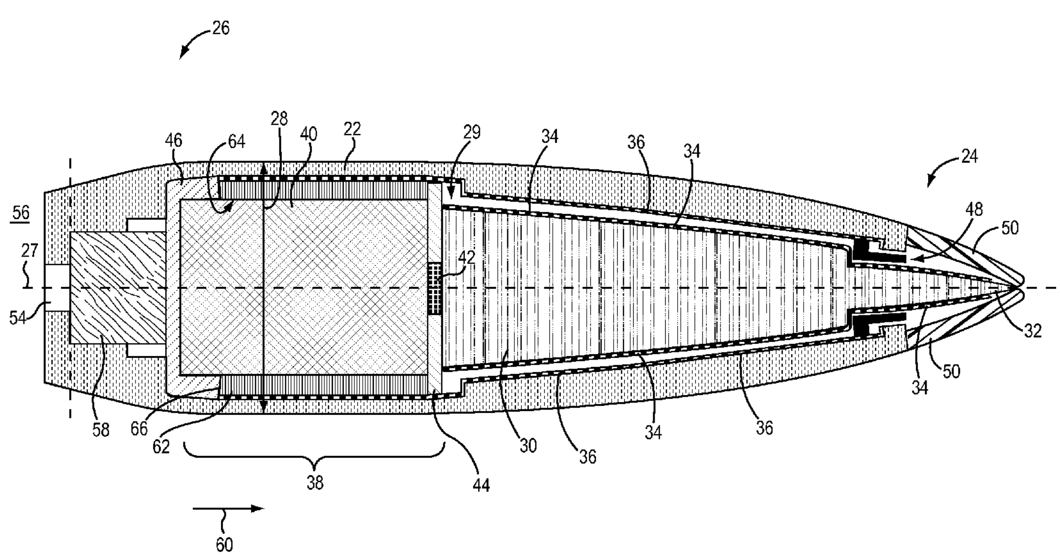
(57) **ABSTRACT**

A reduced drag projectile is provided. The projectile includes a conductive shell that has a leading end and a trailing end. The conductive shell forms an interior volume. The projectile includes a conductive bullet core disposed at least partially within the interior volume. The conductive bullet core has a leading end element and is electrically insulated from the conductive shell. A voltage system is electrically coupled to the conductive shell and electrically coupled to the conductive bullet core. The projectile is configured to expose the leading end element to the atmosphere during flight, and the voltage system is configured to, during flight, generate a voltage at the leading end element that forms a corona discharge at the leading end element.

24 Claims, 9 Drawing Sheets



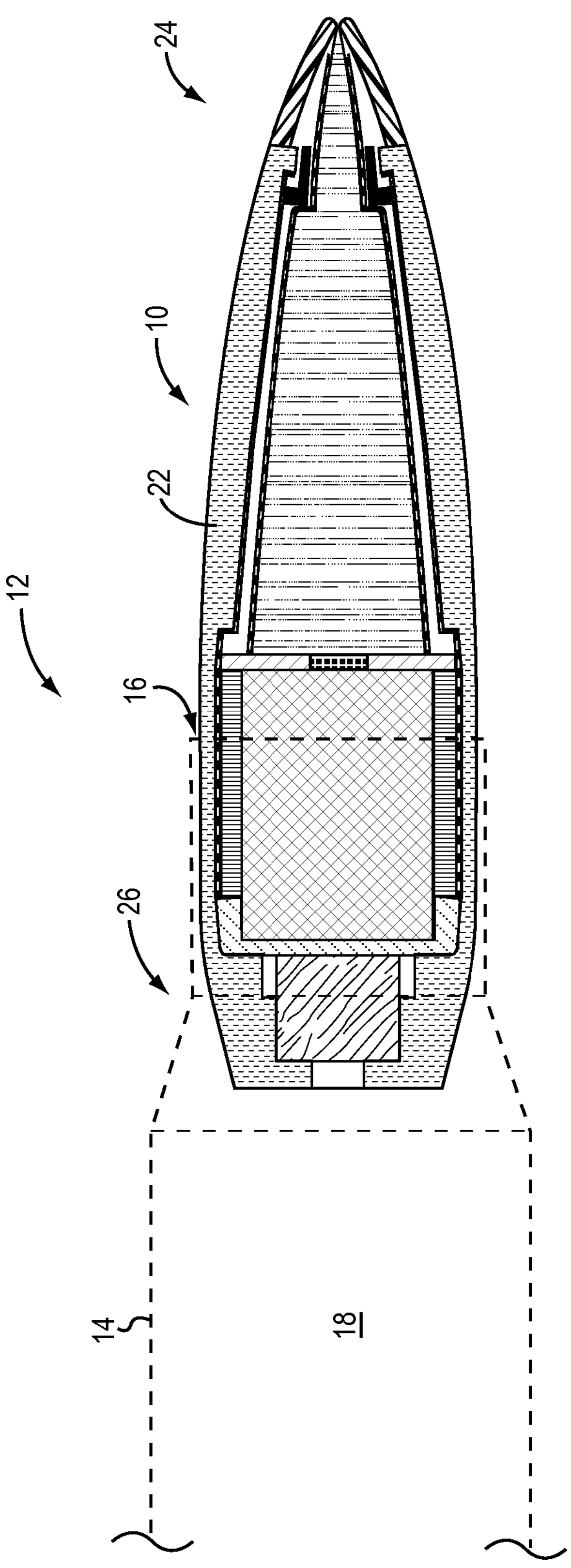


FIG. 1

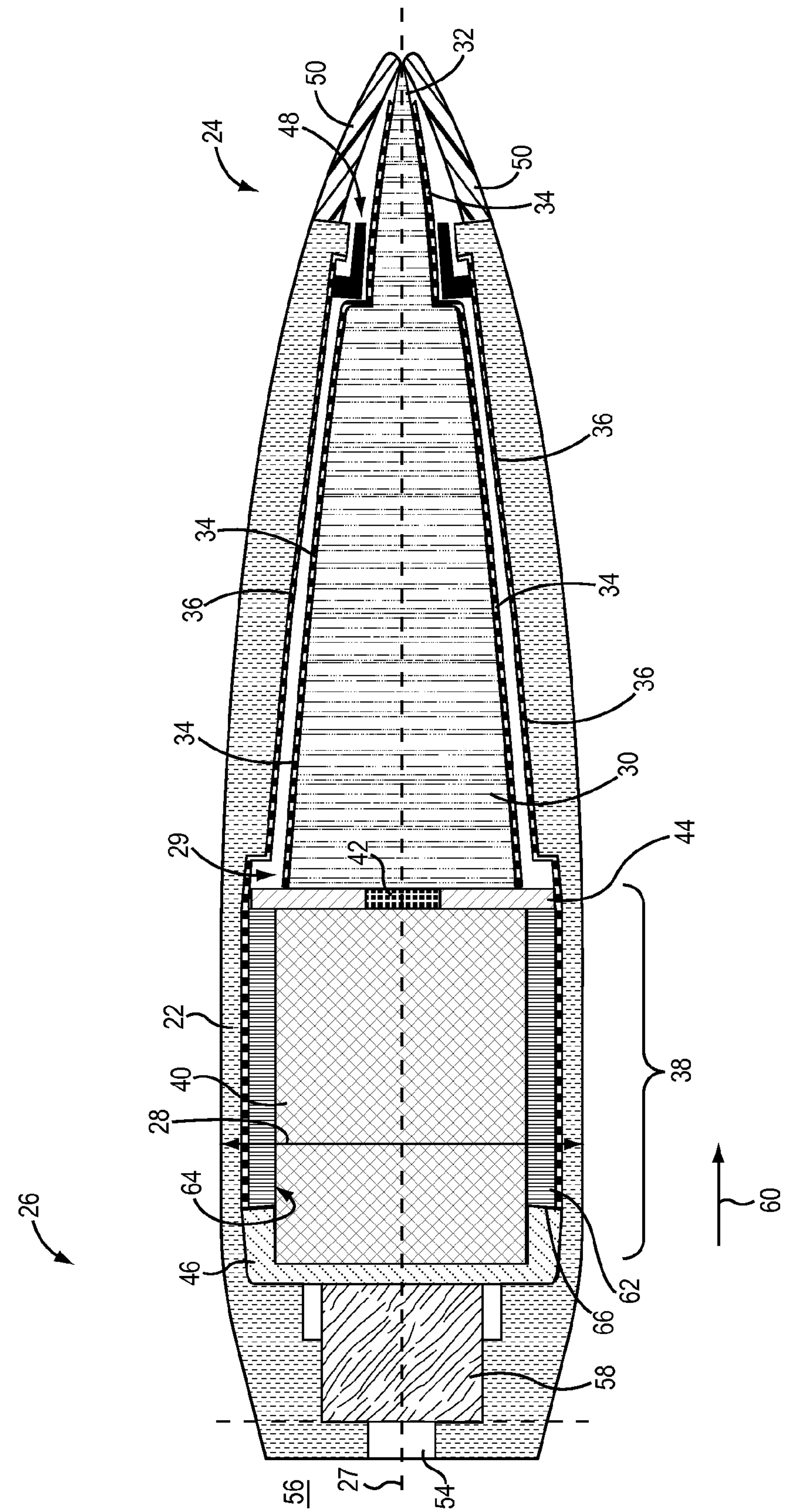


FIG. 2

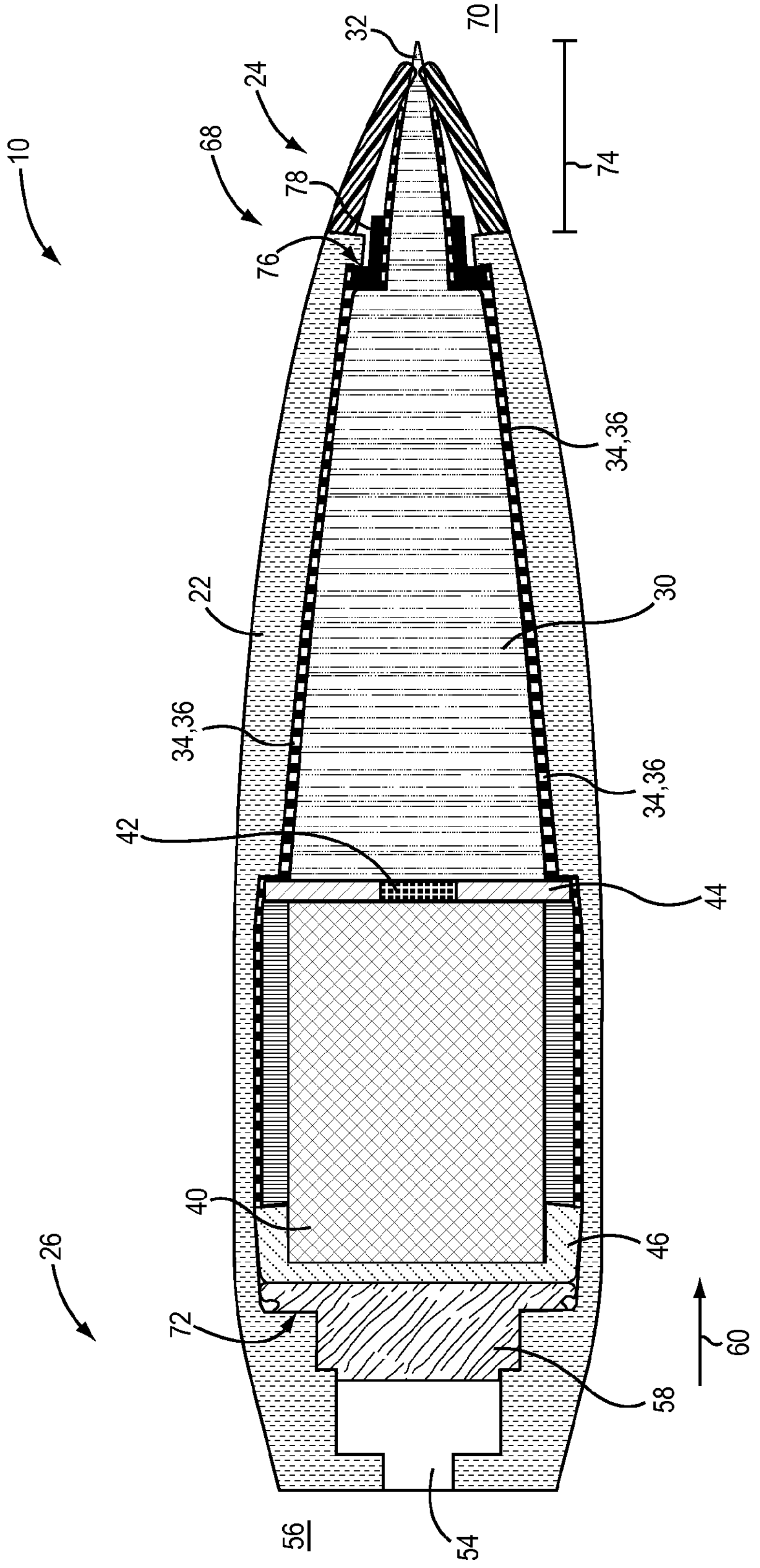

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FIG. 3

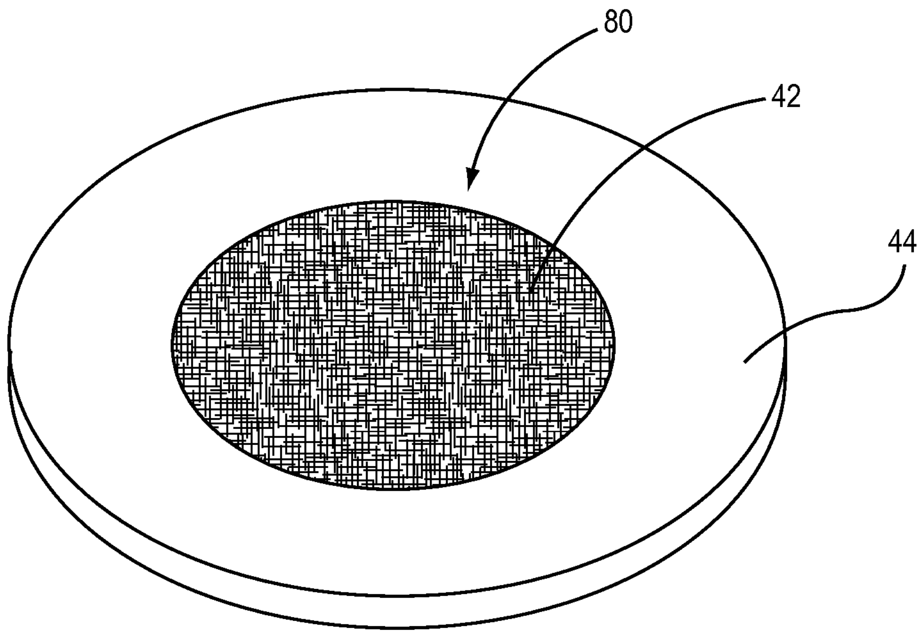

FIG. 4

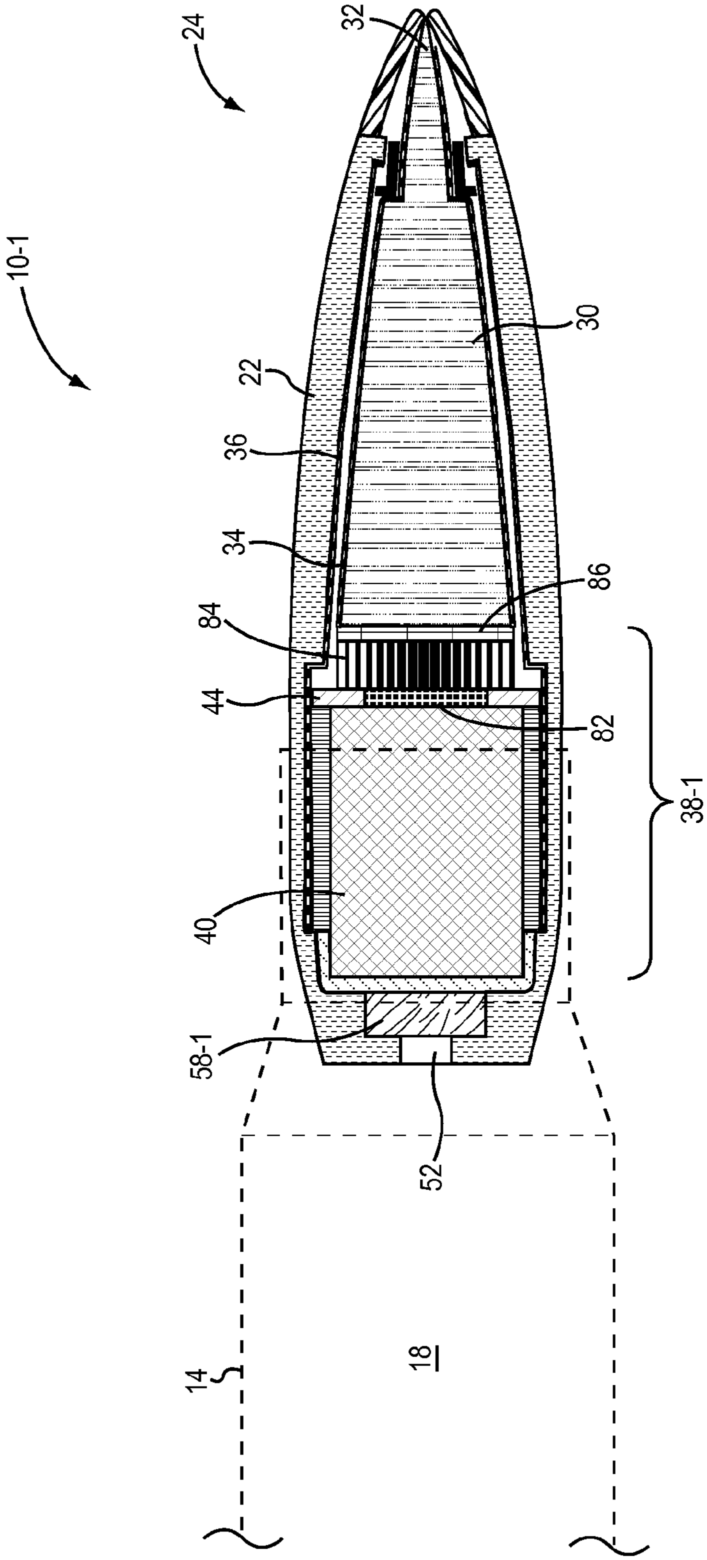

FIG. 5

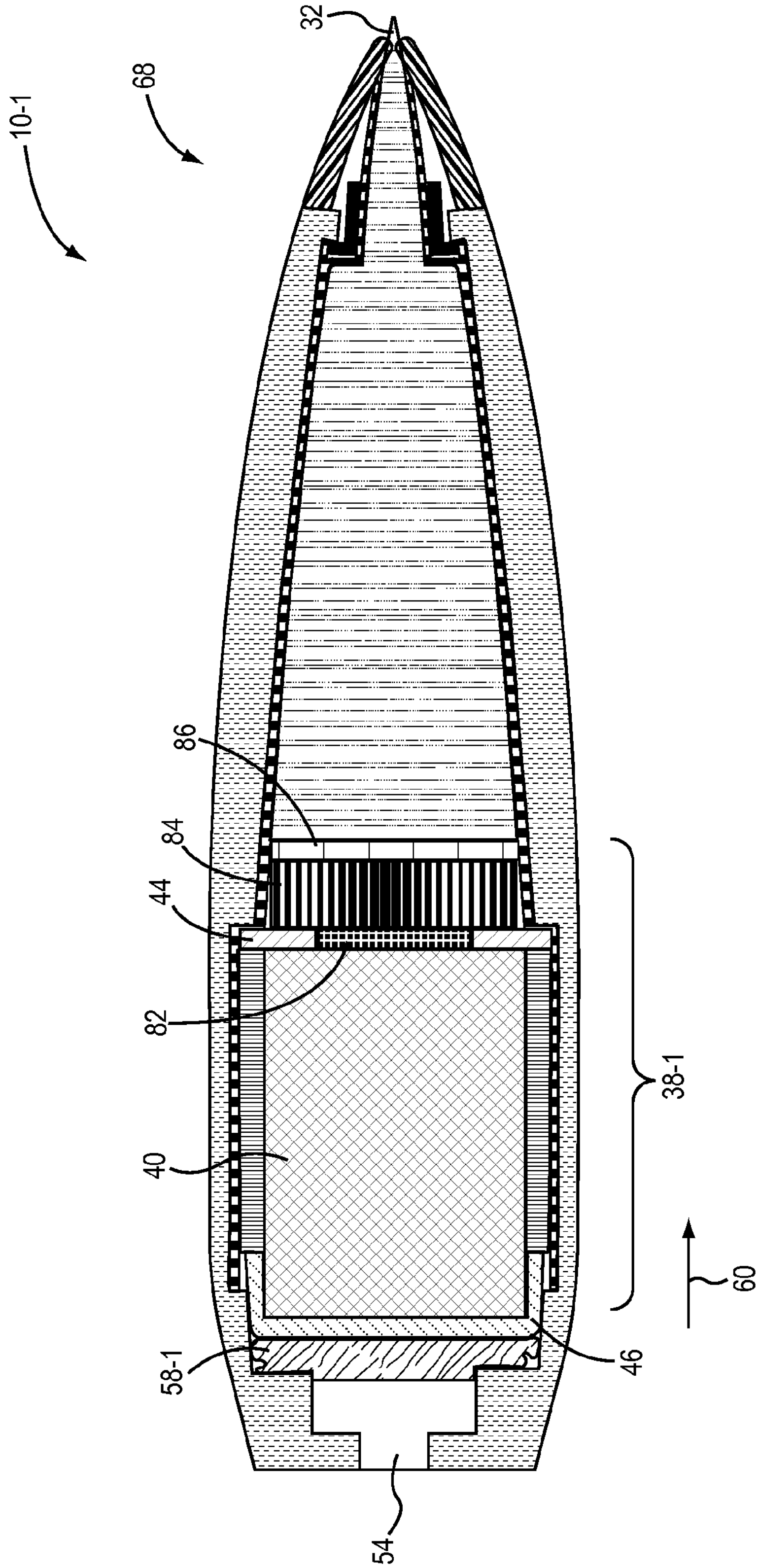

FIG. 6

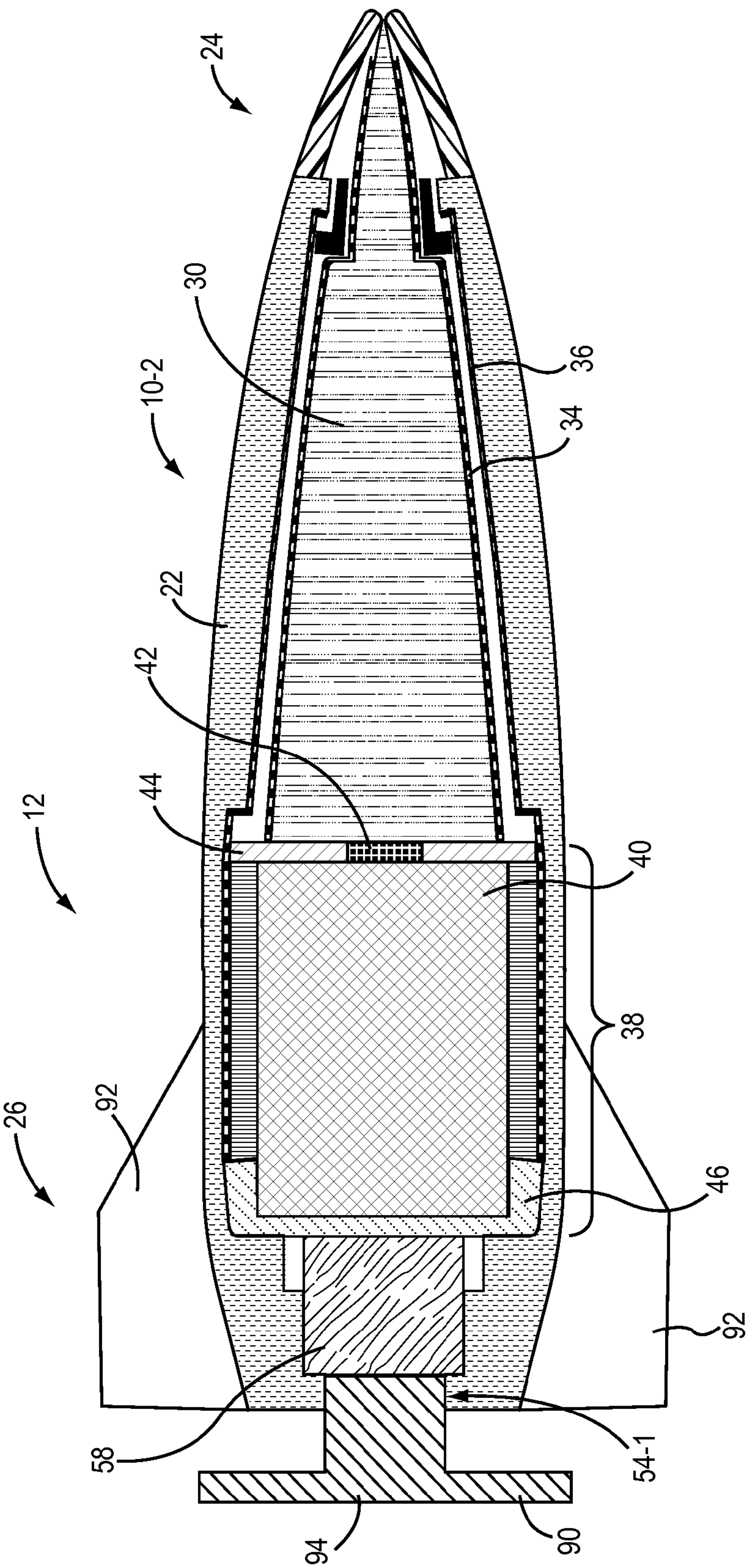

FIG. 7

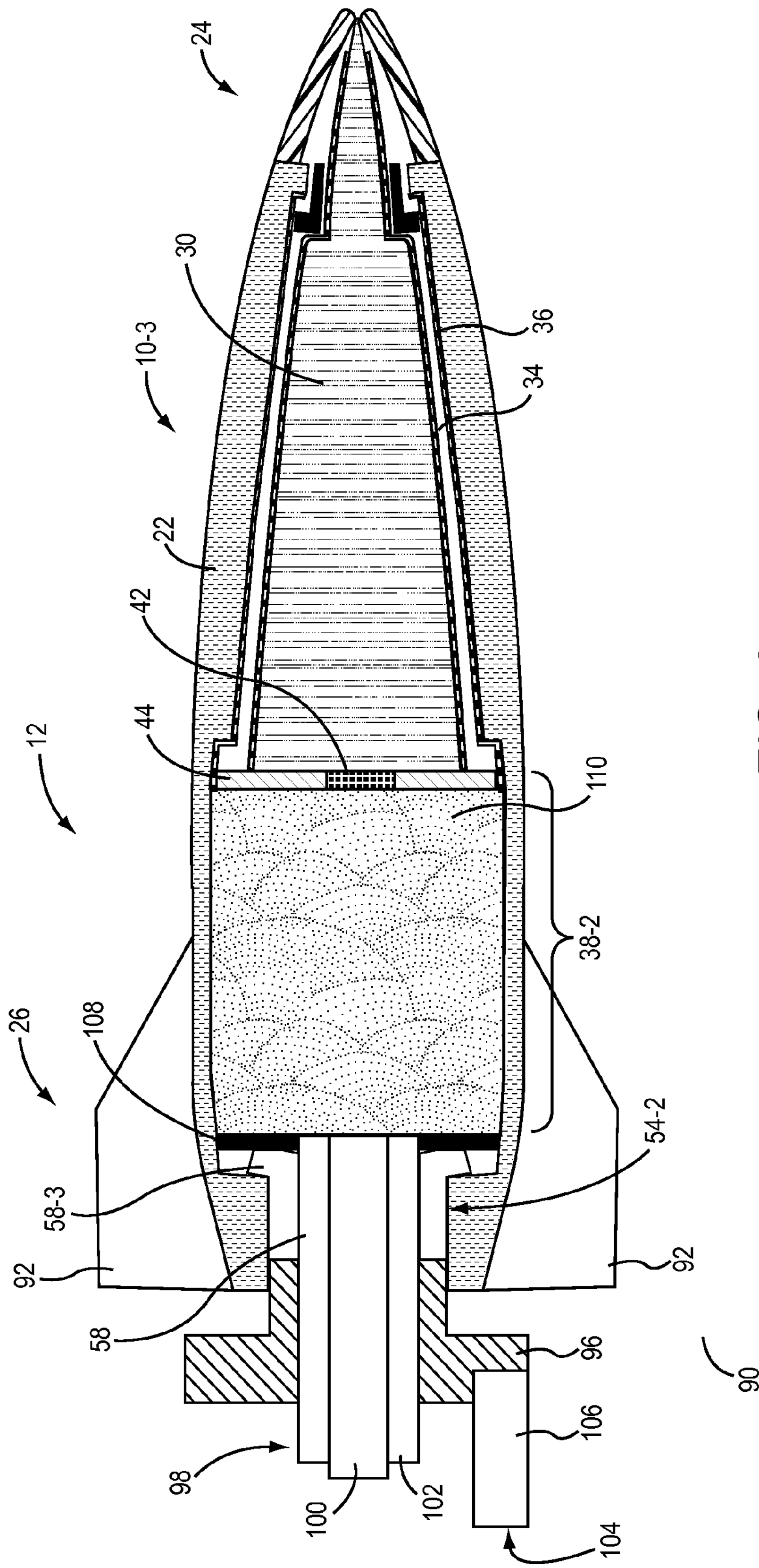
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FIG. 8

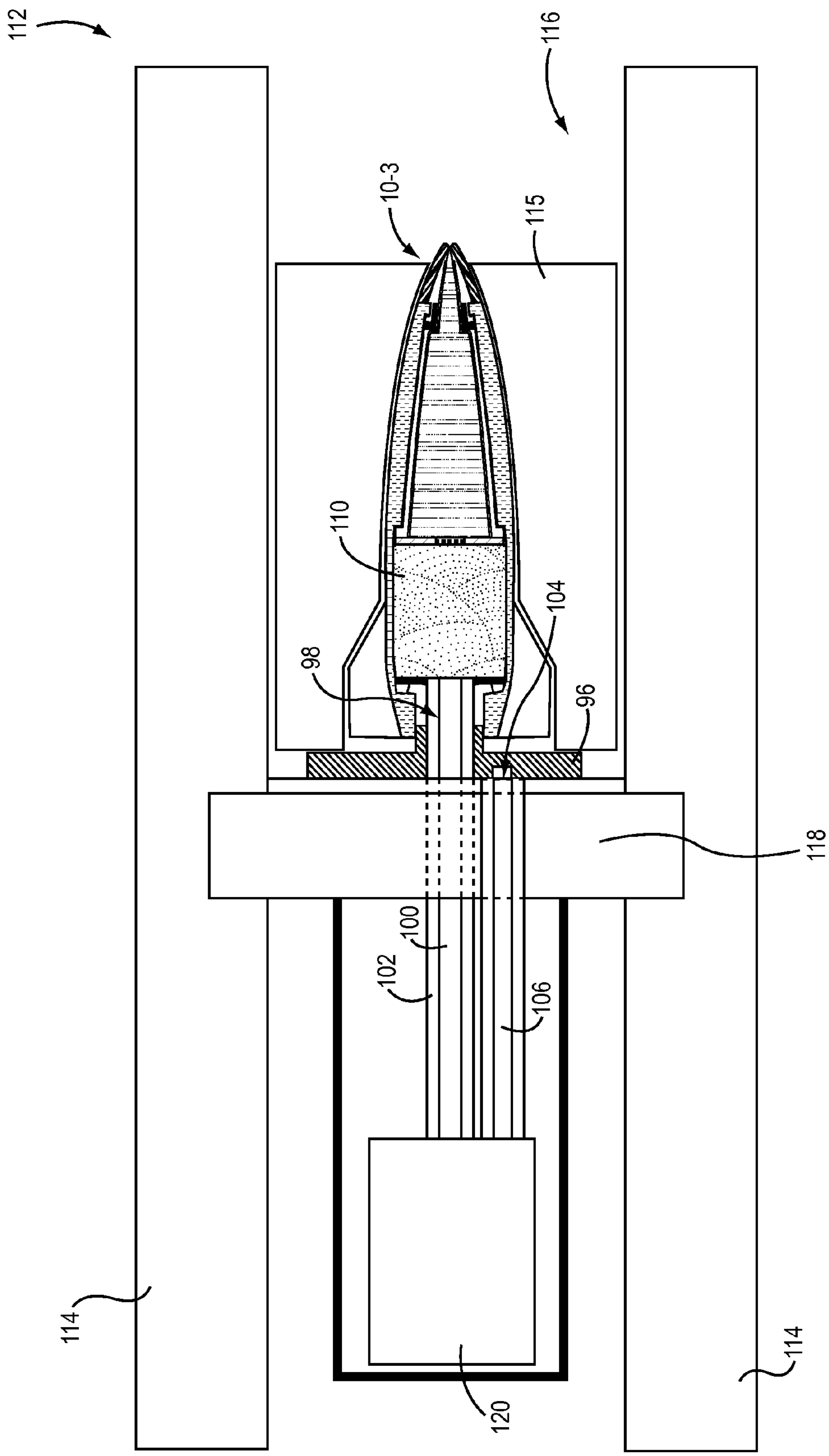

FIG. 9

REDUCED DRAG PROJECTILE

TECHNICAL FIELD

The embodiments relate to projectiles and, in particular, to a reduced drag projectile.

BACKGROUND

"Drag" refers to forces acting opposite to the relative motion of an object moving with respect to a surrounding fluid. In the case of a projectile traveling through the atmosphere, drag is sometimes referred to as air resistance. The range of a projectile discharged into the atmosphere depends in substantial part on drag. The range of a projectile can be increased if drag can be reduced. Moreover, less force is required to launch a projectile a given distance if drag is reduced.

Reducing the drag associated with a projectile provides many advantages. If all other factors remain constant, reducing the drag reduces the amount of accelerant, such as gunpowder, required to propel the projectile a given distance, allowing for a reduction in the size of the cartridge in which the projectile is packaged. Smaller cartridges in turn allow a greater number of cartridges to be carried in the same amount of space, and thus soldiers and law enforcement personnel can carry a greater number of cartridges into an adverse situation than would otherwise be possible. Alternatively, reducing drag while maintaining the same amount of propellant material will increase the range of the projectile. Increasing the range of a projectile may allow the use of a smaller weapon than would otherwise be required to propel the projectile a desired distance. Where the weapon is used by a soldier, increasing the range may allow the threat to be kept at such a distance that lighter body armor may be used.

A corona discharge is a partial breakdown of a dielectric surrounding a point on a high voltage conductor that has a high electrical stress. Studies utilizing supersonic wind tunnels have shown that a corona discharge formed on the leading edge of an object moving with respect to air can reduce the drag of the object.

SUMMARY

The embodiments relate to a reduced drag projectile, wherein a corona discharge is formed at a leading end element of the projectile during flight. The corona discharge reduces drag associated with the projectile and thereby increases range, which allows the projectile to travel a greater distance than would otherwise occur. Moreover, the use of a reduced drag projectile may allow a smaller weapon to be used to discharge the projectile than would otherwise be necessary.

In one embodiment, a projectile is provided. The projectile includes a conductive shell that has a leading end and a trailing end. The conductive shell forms an interior volume. The projectile includes a conductive bullet core disposed at least partially within the interior volume. The conductive bullet core has a leading end element and is electrically insulated from the conductive shell. A voltage system is electrically coupled to the conductive shell and electrically coupled to the conductive bullet core. The projectile is configured to expose the leading end element to the atmosphere during flight, and the voltage system is configured to, during flight, generate a voltage at the leading end element that forms a corona discharge at the leading end element.

In one embodiment, the leading end of the conductive shell forms an opening sized to allow at least a portion of the leading end element to extend beyond the opening.

In one embodiment, the projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation. The projectile includes a non-conductive cap coupled to the leading end of the conductive shell. The non-conductive cap is configured to prevent the leading end element from extending beyond the non-conductive cap in the pre-discharge orientation.

In one embodiment, the voltage system includes a piezoelectric element and a resistor coupled between the piezoelectric element and the conductive bullet core.

In one embodiment, the projectile includes an insulator positioned between the piezoelectric element and the conductive bullet core. The insulator may include an annular opening in which the resistor is disposed. In one embodiment, the insulator comprises sapphire.

In one embodiment, the trailing end of the conductive shell forms an opening between the interior volume and an environment exterior to the trailing end of the conductive shell. The opening is configured to allow pressure generated in the environment to enter the interior volume. In one embodiment, the opening is a predetermined size to allow a predetermined pressure generated in the environment to enter the interior volume.

In one embodiment, the projectile includes a crush piston positioned within the interior volume between the opening and the piezoelectric element. The crush piston is configured to move the piezoelectric element with respect to the conductive shell in a direction toward the leading end of the conductive shell.

In one embodiment, the projectile includes an insulative collar that completely surrounds at least a portion of an outer perimeter of the piezoelectric element and inhibits direct electrical contact between the piezoelectric element and the conductive shell.

In one embodiment, the projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation. The conductive shell has an interior surface configured to halt forward progress of the conductive bullet core with respect to the conductive shell as the conductive bullet core is moved from the pre-discharge orientation to the post-discharge orientation.

In one embodiment, the projectile includes a bearing travel stop configured to engage the interior surface of the conductive shell and to engage the conductive bullet core to halt the forward progress of the conductive bullet core with respect to the conductive shell as the conductive bullet core is moved from the pre-discharge orientation to the post-discharge orientation.

In one embodiment, the conductive shell comprises an interior surface and a polymide film coating disposed on the interior surface. The conductive bullet core comprises an exterior surface and a polymide film coating disposed on the exterior surface. The projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation. In the post-discharge orientation, the polymide film coating disposed on the exterior surface of the conductive bullet core is bonded with the polymide film coating disposed on the interior surface of the conductive shell such that the conductive bullet core is fixed with respect to the conductive shell.

In one embodiment, the voltage system comprises a piezoelectric element and a diode comprising a first diode terminal and a second diode terminal. The first diode terminal is electrically coupled to the piezoelectric element. The voltage system also includes a capacitor that has a first capacitor terminal and a second capacitor terminal. The first capacitor terminal is electrically coupled to the second diode terminal. The voltage system further includes a resistor that includes a first resistor terminal and a second resistor terminal. The first resistor terminal is coupled to the second diode terminal, and the second resistor terminal is coupled to the conductive bullet core.

Those skilled in the art will appreciate the scope of the disclosure and realize additional aspects thereof after reading the following detailed description of the preferred embodiments in association with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawing figures incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

FIG. **1** is a cross-sectional diagram of a reduced drag projectile according to one embodiment;

FIG. **2** is an enlarged cross-sectional diagram of the projectile illustrated in FIG. **1**;

FIG. **3** is a cross-sectional diagram of the projectile illustrated in FIGS. **1** and **2** shown in a post-discharge orientation according to one embodiment;

FIG. **4** is a block diagram of an insulator and a resistor according to one embodiment;

FIG. **5** is a cross-sectional diagram of the projectile shown in a pre-discharge orientation according to another embodiment;

FIG. **6** is a cross-sectional diagram of the projectile illustrated in FIG. **5** shown in a post-discharge orientation according to one embodiment;

FIG. **7** is a cross-sectional diagram of a projectile according to another embodiment;

FIG. **8** is a cross-sectional diagram of a projectile according to another embodiment; and

FIG. **9** is a diagram of an electromagnetic rail gun from which the projectiles illustrated in FIGS. **7** and **8** may be discharged, according to one embodiment.

DETAILED DESCRIPTION

The embodiments set forth below represent the necessary information to enable those skilled in the art to practice the embodiments and illustrate the best mode of practicing the embodiments. Upon reading the following description in light of the accompanying drawing figures, those skilled in the art will understand the concepts of the disclosure and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure and the accompanying claims.

The use herein of ordinals in conjunction with an element is solely for distinguishing what might otherwise be similar or identical labels, such as "first terminal" and "second terminal," and does not imply a priority, a type, an importance, or other attribute, unless otherwise stated herein. The term "about" used herein in conjunction with a numeric value means any value that is within a range of ten percent greater than or ten percent less than the numeric value.

The embodiments relate to a reduced drag projectile, wherein a corona discharge is formed at a leading end element of the projectile during flight. The corona discharge reduces drag associated with the projectile and thereby increases range, which allows the projectile to travel a greater distance than would otherwise occur. Moreover, the use of a reduced drag projectile may allow a smaller weapon to be used to fire the projectile than would otherwise be necessary.

FIG. **1** is a cross-sectional diagram of a reduced drag projectile **10** according to one embodiment. The projectile **10** has a pre-discharge orientation **12**, illustrated in FIGS. **1** and **2**, and a post-discharge orientation illustrated in FIG. **3**. In some embodiments, in the pre-discharge orientation **12**, the projectile **10** may be coupled to a case **14**. The case **14** forms an opening **16** in an interior volume **18**. The interior volume **18** may contain a propellant, such as gun powder, for example (not illustrated). The projectile **10** includes a conductive shell **22** that has a leading end **24** and a trailing end **26**. The trailing end **26** is positioned within the opening **16** and extends at least partially into the interior volume **18**. The case **14** is configured to grip an exterior surface of the trailing end **26** of the projectile **10** to maintain the projectile **10** in the case **14** prior to being discharged.

FIG. **2** is an enlarged cross-sectional diagram of the projectile **10** illustrated in FIG. **1**, with the case **14** omitted for purposes of illustration. The conductive shell **22** comprises a conductive material such as, by way of non-limiting example, copper, brass, copper-clad steel, bronze, or any other suitable conductive material.

The projectile **10** is generally symmetrical about a longitudinal axis **27** and has a greatest diameter **28** perpendicular to the longitudinal axis **27** at some location along the projectile **10**. The greatest diameter **28** may be based on a desired weapon from which the projectile **10** will be discharged. In some embodiments, the projectile **10** is sized to fit a particular caliber barrel, such as a .308 caliber barrel or a 7.62 millimeter (mm) caliber barrel. However, the greatest diameter **28** of the projectile **10** is not limited to sub-1-inch diameters and may comprise a larger diameter for other larger projectiles.

The conductive shell **22** forms an interior volume **29**. A conductive bullet core **30** is disposed at least partially within the interior volume **29** and has a leading end element **32**. The conductive bullet core **30** is electrically insulated from the conductive shell **22**. In particular, in one embodiment, an electric insulator **34** surrounds an exterior perimeter of the conductive bullet core **30**. In one embodiment, the electric insulator **34** may be adhered to the exterior surface of the conductive bullet core **30** prior to assembly of the projectile **10**. Similarly, an interior surface of the conductive shell **22** may be covered by an electric insulator **36**. Again, the electric insulator **36** may be adhered to the interior surface of the conductive shell **22** prior to assembly of the projectile **10**. The electric insulator **34** and the electric insulator **36** may comprise any insulative polymer or material that will bond to the respective conductive surfaces, and to one another when in the post-discharge orientation. The electric insulator **34** and the electric insulator **36** may provide sufficient insulative value to prevent arcing between the conductive bullet core **30** and the conductive shell **22**. The thickness of the electric insulator **34** and the electric insulator **36** may in part be based on the voltage carried by the conductive bullet core **30**. In one embodiment, the electric insulator **34** and the electric insulator **36** comprise a polymide film, such as, by way of non-limiting example, a Kapton® polymide film.

A voltage system **38** is electrically coupled to the conductive shell **22** and electrically coupled to the conductive bullet core **30**. The projectile **10** is configured to expose a leading end element **32** to the atmosphere during flight. The voltage system **38** is configured to, during flight, generate a voltage at the leading end element **32** that forms a corona discharge at the leading end element **32**. In some embodiments, the corona discharge may be formed for several seconds. In other embodiments, where the conductive shell **22** has a relatively large diameter, such as in the case of the projectile **10** being used in a cannon, the corona discharge may last substantially longer, such as more than a minute. While the corona discharge is formed, the drag associated with the projectile **10** traveling through the atmosphere is reduced, increasing the range of the projectile **10**.

The conductive bullet core **30** may comprise any desired material, such as, by way of non-limiting example, tungsten, molybdenum, niobium, tantalum, rhenium, depleted uranium, or steel.

In one embodiment, the voltage system **38** includes a piezoelectric element **40** and a current-limiting resistor **42**. The current-limiting resistor **42** limits the electrical current powering the corona discharge such that the corona discharge is sufficient to reduce drag for a relatively extended period of time. In one embodiment, the piezoelectric element **40** is about 6 mm in diameter, is about 15 mm in length, has a density of about 7.7, and weighs about 50 grains. However, it is apparent that the piezoelectric element **40** may be sized depending on the particular application. The resistor **42** is configured to provide sufficient current for a corona discharge to form at the leading end element **32** for a desired period of time, such as, by way of non-limiting example, 2-3 seconds. In one embodiment, the resistor **42** is disposed in an insulator **44** that electrically insulates the conductive bullet core **30** from the piezoelectric element **40**. In one embodiment, the piezoelectric element **40** is electrically coupled to the conductive shell **22** via an annular metal guide **46**.

The conductive shell **22** forms an opening **48** that is sized to allow at least a portion of the leading end element **32** to extend beyond the opening **48**. The projectile **10** also includes a non-conductive cap **50** that is coupled to the leading end **24** of the conductive shell **22**. The non-conductive cap **50** is configured to prevent the leading end element **32** from extending beyond the non-conductive cap **50** in the pre-discharge orientation **12**. The non-conductive cap **50** creates a distance between the leading end element **32** and the conductive shell **22** during flight of the projectile **10** and also protects accidental contact between an object, such as a body part, and the leading end element **32**. In some embodiments, the leading end element **32** is relatively sharp and has a radius less than about 30 to about 50 microns. In other embodiments, the leading end element **32** may have a radius greater than about 30 to about 50 microns; however, a leading end element **32** having a larger radius will utilize a higher voltage, which may decrease the duration of the corona discharge.

The trailing end **26** of the conductive shell **22** forms an opening **54** between the interior volume **29** and an environment **56** that is exterior to the trailing end **26** of the conductive shell **22**. The opening **54** is configured to allow pressure generated in the environment **56** to enter the interior volume **29**. The environment **56** may initially comprise, for example, the interior volume **18** of the case **14** during the discharge process. After the projectile **10** is discharged from the case **14**, the environment **56** may include an interior volume inside a barrel, such as a rifle barrel. In some embodiments, the opening **54** is a predetermined size that allows the predetermined pressure generated in the environment **56** to enter the interior volume **29** via the opening **54**.

The projectile **10** includes a crush piston **58** positioned within the interior volume **29** between the opening **54** and the piezoelectric element **40**. The crush piston **58** is configured to, in response to pressure entering the opening **54**, move the piezoelectric element **40** with respect to the conductive shell **22** in a direction **60** toward the leading end **24** of the conductive shell **22**. The projectile **10** also includes an insulative collar **62** that surrounds at least a portion of an outer perimeter **64** of the piezoelectric element **40**. The insulative collar **62** prevents or otherwise inhibits direct electrical contact between the piezoelectric element **40** and the conductive shell **22** along such portion of the outer perimeter **64**. In one embodiment, the annular metal guide **46** is positioned between the piezoelectric element **40** and the crush piston **58**. The annular metal guide **46** is in electrical contact with the piezoelectric element **40** and the conductive shell **22**.

In one embodiment, the annular metal guide **46** includes an annular edge **66** that is in contact with the insulative collar **62**. The annular edge **66** is configured to urge the insulative collar **62** in the direction **60** toward the leading end **24** of the conductive shell **22**.

FIG. **3** is a cross-sectional diagram of the projectile **10** illustrated in FIGS. **1** and **2** shown in a post-discharge orientation **68**, according to one embodiment. As pressure from the environment **56** builds up in the opening **54**, the crush piston **58** is urged forward in the direction **60**. The exterior surface of the conductive shell **22** experiences frictional forces with the barrel of the weapon in which the projectile **10** is being discharged. Consequently, the crush piston **58** moves the annular metal guide **46** with respect to the conductive shell **22** in the direction **60**, which in turn moves the piezoelectric element **40**, the insulator **44**, and the conductive bullet core **30** forward with respect to the conductive shell **22**. The leading end element **32** moves past the end of the non-conductive cap **50** and is exposed to an atmosphere **70** upon exiting the barrel of the weapon. The crush piston **58** is preferably made of a metal, such as copper or the like, which deforms under sufficient pressure. The crush piston **58** causes the annular metal guide **46** to move with respect to the conductive shell **22**. The crush piston **58** at least partially fills the void formed between the annular metal guide **46** and an interior surface **72** of the conductive shell **22** and maintains pressure against the annular metal guide **46**. This pressure in turn compresses the piezoelectric element **40**, generating a voltage.

One terminal of the piezoelectric element **40** is electrically coupled to the conductive bullet core **30** via the resistor **42**, and another terminal of the piezoelectric element **40** is coupled to the conductive shell **22** via the annular metal guide **46**, creating a voltage between the leading end element **32** and the conductive shell **22**. Due to the distance **74** between the leading end element **32** and the conductive shell **22** and the relatively small radius of the leading end element **32**, an electrical overstress condition occurs at the leading end element **32**, and a corona discharge is formed during flight of the projectile **10**.

In one embodiment, the conductive shell **22** includes an interior surface **76** that is configured to halt forward progress of the conductive bullet core **30** with respect to the conductive shell **22** as the conductive bullet core **30** is moving from the pre-discharge orientation **12** to the post-discharge orientation **68**. In one embodiment, the projectile **10** includes a bearing travel stop **78** that is configured to engage the interior surface **76** of the conductive shell **22** and to engage the conductive bullet core **30** to halt the forward progress of the conductive bullet core **30** with respect to the conductive shell **22** as the conductive bullet core **30** is moving from the pre-discharge orientation **12** to the post-discharge orientation **68**. In one embodiment, the bearing travel stop **78** comprises sapphire.

In one embodiment, in the post-discharge orientation **68**, the electric insulators **34**, **36** bond due to the temperatures and pressures generated as the conductive bullet core **30** is urged forward with respect to the conductive shell **22**, such that the conductive bullet core **30** becomes fixed with respect to the conductive shell **22**. Fixing the conductive bullet core **30** with respect to the conductive shell **22** enables the conductive bullet core **30** to rotate with the rotation of the conductive shell **22** as rifling in the barrel through which the projectile **10** is discharged imparts rotational forces upon the projectile **10**.

FIG. **4** is a block diagram of the insulator **44** and resistor **42** according to one embodiment. As discussed above, the insulator **44** inhibits electrical contact between the conductive bullet core **30** and the piezoelectric element **40**, ensuring any electric current flow between the conductive bullet core **30** and the piezoelectric element **40** occurs via the resistor **42**. In this embodiment, the insulator **44** is annular and forms an opening **80** at a center of the insulator **44**. The resistor **42** is disposed in the opening **80** and allows the electric current to flow from the piezoelectric element **40** to the conductive bullet core **30** when the piezoelectric element **40** is stressed or otherwise deformed. As discussed above, the insulator **44** may comprise any suitable insulative material, including, by way of non-limiting example, sapphire, fused aluminum oxide, ceramic, or porcelain.

FIG. **5** is a cross-sectional diagram of a projectile **10-1** according to another embodiment. The projectile **10-1** is substantially similar or identical to the projectile **10** discussed above with regard to FIGS. **1-4**, unless otherwise specifically stated herein. In this embodiment, the projectile **10-1** includes a diode **82** comprising a first diode terminal and a second diode terminal and positioned within the insulator **44**. The first diode terminal is electrically coupled to the piezoelectric element **40**. The second diode terminal is electrically coupled to a capacitor **84**. The capacitor **84** comprises a supercapacitor or an ultracapacitor. The capacitor **84** has a first capacitor terminal that is electrically coupled to the second diode terminal and a second capacitor terminal that is coupled to a resistor **86**. The resistor **86** has a first resistor terminal that is coupled to the second diode terminal and a second resistor terminal that is coupled to the conductive bullet core **30**.

FIG. **6** is a cross-sectional diagram of the projectile **10-1** in the post-discharge orientation **68**. In this embodiment, a crush piston **58-1** urges the annular metal guide **46** forward with respect to the conductive shell **22** in the direction **60**. The piezoelectric element **40** is jolted by the crush piston **58-1** and generates a current, which flows through the diode **82** into the supercapacitor **84**. The supercapacitor **84** releases voltage via the resistor **86** to the conductive bullet core **30** to form a corona discharge at the leading end element **32**.

In one embodiment, the electrical connections between the elements that make up the voltage systems **38**, **38-1** may be maintained by the pressure exerted by the crush pistons **58**, **58-1**, respectively. In another embodiment, a ribbon of copper or other conductive material may be soldered or welded between each such element to prevent any bounce or jarring from disconnecting the electrical connections momentarily.

Example Embodiment

As an example for sizing the piezoelectric element **40** to generate a corona discharge at the leading end element **32** during flight of the projectile **10**, **10-1**, assume the following:

1) The projectile **10**, **10-1** will be sized to fit in a 7.62 mm barrel.

2) A maximum reasonable size for a cylindrical piezoelectric element **40** contained within a 7.62 mm diameter projectile is 6.0 mm in diameter and 15 mm in length.

In this example, 0.424 joules of energy are available, in accordance with the following formula.

V (voltage)=π times (×) radius(r)^2×height (h)=$\pi\times(0.60)^2\times 1.50=0.424\ \text{cm}^2=0.424$ joules. A leading end element **32** having a sufficiently sharp tip, such as having a radius less than or equal to 35 microns, can maintain a negative discharge in air at an atmospheric pressure of about 4,500 volts. It will be assumed, from a conservative approach, that 9,500 volts are needed to produce a corona discharge at Mach 2.5 from such a leading end element **32**. It will further be assumed that 15 microamperes are sufficient to maintain the corona discharge for the projectile **10**, **10-1**. Note that 1 Watt=1 Joule/second. P (power)=9.5×10^3 volts$\times1.5\times10^{-5}$ amps=0.143 watts=0.143 joules/second. Therefore, in this example, 0.143 Joules/second are needed to maintain a corona discharge at the leading end element **32**. Because 0.424 joules of energy are available, the corona discharge would be formed at the leading end element **32** for a maximum of about 2.97 seconds, in this example.

FIG. **7** is a cross-sectional diagram of the projectile **10-2** according to another embodiment. The projectile **10-2** is substantially similar to the projectiles **10**, **10-1** except as otherwise stated herein. In this embodiment, the projectile **10-2** may be discharged via a trolley, or armature, such as may be used in a field cannon, a tank cannon, or an electromagnetic rail gun, for example. The projectile **10-2** has an opening **54-1** that is sized to allow the entry of a launch plug **90** to enter the conductive shell **22** and contact the crush piston **58**. The projectile **10-2** may also include one or more fins **92** for purposes of aerodynamic stabilization. The projectile **10-2** may be utilized, by way of non-limiting example, with a tank cannon or electromagnetic rail gun. During discharge of the projectile **10-2**, a surface **94** of the launch plug **90** is positioned against the particular launching mechanism. As the launching mechanism urges the launch plug **90** in the direction of flight, the launch plug **90** urges the crush piston **58** against the annular metal guide **46**, which in turn compresses or otherwise deforms the piezoelectric element **40** to generate electricity. In some embodiments, the projectile **10-2** may be contained within a sabot when discharged.

FIG. **8** is a cross-sectional diagram of a projectile **10-3** according to another embodiment. In this embodiment, the projectile **10-3** is launched via an electromagnetic rail gun (not illustrated). The projectile **10-3** is substantially similar to the projectiles **10**, **10-1**, **10-2** except as otherwise stated herein. Again, the projectile **10-3** may be enclosed in a sabot (not illustrated) when discharged. The projectile **10-3** may include the fins **92** for aerodynamic stabilization. The projectile **10-3** includes an opening **54-2** sized to receive a hollow plug **96** that is electrically conductive and is in electrical contact with the conductive shell **22**. In this embodiment, the hollow plug **96** is coupled directly or indirectly to an armature (not illustrated) of the rail gun that moves rapidly down the rails upon discharge. A coil (not illustrated) is passed through the electromagnetic field that exists between the rails during operation. The coil includes a first coil end **98**, which extends through an opening in the hollow plug **96** and makes electrical contact with a capacitor **110** to charge the capacitor **110** during discharge. The first coil end **98** includes a conductor **100** and an insulator **102** to prevent the conductor **100** from coming into electrical contact with the hollow plug **96**.

A second coil end **104** includes a conductor **106** that is in electrical contact with the hollow plug **96**. During discharge, a crush piston **58-3** contacts a support structure **108**, which contacts the capacitor **110**. As the coil moves through the electromagnetic field generated during operation of the electromagnetic rail gun, a current is produced that travels via the first coil end **98** into the capacitor **110** to charge the capacitor **110**.

The capacitor **110** may comprise any suitable type of capacitor or capacitors. If the capacitor **110** is a concentric capacitor, the capacitor **110** need not be insulated from the conductive shell **22**. If the capacitor **110** is a stacked capacitor design, the capacitor **110** should be insulated from the conductive shell **22**.

FIG. **9** is diagram of a rail gun **112** according to one embodiment. The rail gun **112** comprises a plurality of rails **114**. While only two rails **114** are illustrated, the rail gun **112** may comprise any desired number of rails **114**. Prior to discharge, the projectile **10-3** is enclosed within a sabot **115** and positioned in a volume **116** between the rails **114** and coupled to an armature **118** via the hollow plug **96**. The first coil end **98** is connected to the capacitor **110**, and the second coil end **104** is connected to the hollow plug **96**. The first coil end **98** and the second coil end **104** are electrically coupled to a coil **120** that moves through the electromagnetic field created in the volume **116** during discharge of the projectile **10-3**. During discharge, the projectile **10-3** ultimately separates from the first coil end **98** and the second coil end **104**.

Among other advantages, the embodiments increase the effective range of the projectiles **10**, **10-1**, **10-2**, **10-3** by reducing aerodynamic drag during the flight of the projectiles **10**, **10-1**, **10-2**, **10-3**. Increased effective range in this manner does not require increasing muzzle velocity or utilizing a larger caliber weapon. Increasing muzzle velocity via other mechanisms, such as by increasing an amount of propellant, decreases barrel life and increases recoil, as well as the size of the case, thereby limiting the amount of ammunition that can be transported.

It should be noted that the number of Joules of electrical energy available for the corona discharge is in part dependent on the volume of the piezoelectric element **40** or capacitors **84**, **110**. Depending on projectile configuration, the volume of the energy storage medium will increase based on the square of the increase in diameter of the projectiles **10**, **10-1**, **10-2**, **10-3**. Therefore, the time duration of the corona discharge will increase substantially for larger projectiles **10**, **10-1**, **10-2**, **10-3**. Even allowing for the increased current needed to provide the drag reduction for larger projectiles **10**, **10-1**, **10-2**, **10-3**, the reduced drag can be expected to exceed one minute for larger diameters projectiles **10**, **10-1**, **10-2**, **10-3**, such as a cannon round.

In some embodiments, the projectiles **10**, **10-1**, **10-2**, **10-3** may be packaged with a sabot that protects the leading end element **32** prior to discharge but which separates from the projectile **10-2** at some point post-discharge, thereby exposing the leading end element **32** to the atmosphere during flight. In such embodiments, the conductive bullet core **30** need not be moved with respect to the conductive shell **22**.

Those skilled in the art will recognize improvements and modifications to the preferred embodiments of the disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

What is claimed is:

1. A projectile comprising:

a conductive shell having a leading end and a trailing end, the conductive shell forming an interior volume;

a conductive bullet core disposed at least partially within the interior volume and having a leading end element, the conductive bullet core electrically insulated from the conductive shell;

a voltage system coupled to the conductive bullet core; and

wherein the projectile is configured to expose the leading end element to an atmosphere during flight and the voltage system is configured to, during flight, generate a voltage at the leading end element that forms a corona discharge at the leading end element.

2. The projectile of claim **1**, wherein the leading end of the conductive shell forms an opening sized to allow at least a portion of the leading end element to extend beyond the opening.

3. The projectile of claim **2**, wherein the projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation, and further comprising a non-conductive cap coupled to the leading end of the conductive shell, the non-conductive cap configured to prevent the leading end element from extending beyond the non-conductive cap in the pre-discharge orientation.

4. The projectile of claim **1**, wherein the voltage system comprises:

a piezoelectric element; and

a resistor coupled between the piezoelectric element and the conductive bullet core.

5. The projectile of claim **4**, further comprising an insulator positioned between the piezoelectric element and the conductive bullet core.

6. The projectile of claim **5**, wherein the insulator comprises a sapphire insulator, is annular, and forms an opening at a center of the sapphire insulator, and wherein the resistor is disposed in the opening.

7. The projectile of claim **4**, wherein the trailing end of the conductive shell forms an opening between the interior volume and an environment exterior to the trailing end of the conductive shell, the opening configured to allow pressure generated in the environment to enter the interior volume.

8. The projectile of claim **7**, wherein the opening comprises a predetermined size to allow a predetermined pressure generated in the environment to enter the interior volume.

9. The projectile of claim **4**, further comprising:

a crush piston positioned within the interior volume between the opening and the piezoelectric element, the crush piston configured to move the piezoelectric element with respect to the conductive shell in a direction toward the leading end of the conductive shell.

10. The projectile of claim **9**, further comprising an insulative collar that completely surrounds at least a portion of an outer perimeter of the piezoelectric element and prevents direct electrical contact between the piezoelectric element and the conductive shell.

11. The projectile of claim **10**, further comprising an annular metal guide positioned between the piezoelectric element and the crush piston, the annular metal guide in electrical contact with the voltage system and the conductive shell.

12. The projectile of claim **11**, wherein the annular metal guide comprises an annular edge in contact with the insulative collar, the annular metal guide configured to urge the insulative collar in the direction toward the leading end of the conductive shell.

13. The projectile of claim **1**, wherein the projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation, and the conductive shell has an interior surface configured to halt forward progress of the conductive bullet core with respect to the conductive shell as the conductive bullet core is moved from the pre-discharge orientation to the post-discharge orientation.

14. The projectile of claim **13**, further comprising a bearing travel stop configured to engage the interior surface of the conductive shell and the conductive bullet core to halt the forward progress of the conductive bullet core with respect to the conductive shell as the conductive bullet core is moved from the pre-discharge orientation to the post-discharge orientation.

15. The projectile of claim **14**, wherein the bearing travel stop comprises sapphire.

16. The projectile of claim **1**, wherein:

the conductive shell comprises an interior surface and further comprises a polymide film coating disposed on the interior surface;

the conductive bullet core comprises an exterior surface and further comprises a polymide film coating disposed on the exterior surface;

the projectile has a pre-discharge orientation and a post-discharge orientation that is different from the pre-discharge orientation; and

in the post-discharge position, the polymide film coating disposed on the exterior surface of the conductive bullet core is bonded with the polymide film coating disposed on the interior surface of the conductive shell, such that the conductive bullet core is fixed with respect to the conductive shell.

17. The projectile of claim **1**, further comprising:

a case forming an opening and an interior volume;

a propellant disposed in the interior volume; and

wherein the trailing end of the conductive shell is positioned within the opening and extends into the interior volume, and wherein the case is configured to grip the trailing end of the conductive shell.

18. The projectile of claim **1**, wherein the voltage system comprises:

a piezoelectric element;

a diode comprising a first diode terminal and a second diode terminal, the first diode terminal electrically coupled to the piezoelectric element;

a capacitor comprising a first capacitor terminal and a second capacitor terminal, the first capacitor terminal electrically coupled to the second diode terminal;

a resistor comprising a first resistor terminal and a second resistor terminal, the first resistor terminal coupled to the second diode terminal and the second resistor terminal coupled to the conductive metal core.

19. The projectile of claim **1**, wherein the leading end element has a radius of less than about 50 microns.

20. The projectile of claim **1**, wherein the conductive shell is symmetrical about a longitudinal axis, and has a greatest radius in a plane perpendicular to the longitudinal axis of 7.62 millimeters (mm).

21. The projectile of claim **1**, wherein the voltage system has a first terminal electrically coupled to the conductive shell and a second terminal electrically coupled to the conductive bullet core.

22. The projectile of claim **1**, wherein the trailing end of the conductive shell forms an opening between the interior volume and an environment exterior to the trailing end of the conductive shell, the opening configured to receive a launch plug associated with a launching mechanism.

23. The projectile of claim **1**, wherein the voltage system comprises a capacitor configured to be electrically coupled to a coil end of a coil during a discharge of the projectile to receive an electric charge during the discharge of the projectile.

24. A projectile comprising:

a conductive shell forming an interior volume;

a conductive bullet core disposed at least partially within the interior volume and having a leading end element, the conductive bullet core electrically insulated from the conductive shell; and

a voltage system disposed within the interior volume having a first terminal electrically coupled to the conductive shell and a second terminal electrically coupled to the conductive bullet core, the voltage system configured to provide a voltage at the leading end element during flight of the projectile to form a corona discharge at the leading end element.

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